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ABSTRACT

One of the major payloads to be considered for delivery to orbit by the Space Shuttle is a cryogenic propulsion stage.

An investigation was conducted, in conjunction with North American Rockwell, to investigate the interfaces between the Centaur and the Shuttle and the various possible operational modes of launching the Centaur in the Shuttle. The Centaur vehicle was used as the design model since its characteristics are presently well defined and it accommodates all the unmanned missions in the time period of interest.

The results of the study showed Centaur integration into the Space Shuttle to be feasible with minimum additional GSE and operational complexity.

INTRODUCTION

The optimum method of incorporating a cryogenic upper stage into the Space Transportation System is dependent upon both performance and operational considerations. Many studies have been conducted in evaluating vehicle sizing, stage performance, and mission capture capability, but few operational studies of sufficient depth to be of use to the Shuttle designers have been conducted. The requirements for carrying a cryogenic stage in the cargo bay must be identified early enough in the program to assure that the Shuttle, and its supporting equipment, will accommodate the high energy stage.

A study was recently conducted, in conjunction with North American Rockwell, to establish some basic criteria and identify items requiring further definition in the interface and operational areas. The purpose of this paper is to summarize some of the major results of this study and to identify some of the major factors affecting the selection of the proper operating mode. The Centaur was used as the model vehicle since its characteristics and requirements have been established, allowing a realistic assessment of impact on Shuttle design. The Centaur is also of sufficient size and performance to accommodate all the unmanned missions in the time period of interest.

The results of the study showed that the Centaur integration into the Space Shuttle is feasible with a minimum of additional GSE and operational complexity although the final selection of the best operating mode of the Centaur cannot be established until requirements, capability, facility definition, and operating mode of the selected Shuttle configuration are phased into continuing Centaur integration studies.

BACKGROUND

The baseline mission of the Space Shuttle is the delivery of payloads to low earth circular orbits. There remains a great variety of missions which cannot be accommodated solely by the Space Shuttle in this mode, and require an additional propulsive stage to provide the required mission ΔV. These missions can generally be classified in four categories as shown in Figure 1 and are identified as follows:

1. Low to intermediate earth orbit

2. Synchronous equatorial

3. Planetary injection

4. Lunar

The first three categories are of immediate interest when considering the use of the present Centaur in an expendable unmanned mode. The study herein described assumes that the Centaur is operated in an unmanned expendable mode, although the use of the Centaur in a reusable mode should have minimal impact on the results of the study since it is concerned primarily with the launch aspects of the Shuttle/Booster combination.

A typical mission model, based on USAF and NASA information, was used to provide the traffic distribution shown in Figure 2. Only unmanned missions are considered in this distribution chart, and the traffic is differentiated into two areas – those missions which can be flown by the Space Shuttle alone and those requiring the additional performance of an Orbit-to-Orbit Shuttle. An Orbit-to-Orbit Shuttle is required for 305 flights (excluding 28 retrieval missions). The importance of these flights (i.e., payloads) and frequency of occurrence require early consideration of their requirements to assure compatibility of Shuttle integration.

The performance capability of the Centaur is shown in Figure 3. This performance allows the Centaur to accomplish all 305 expendable missions. The USAF requirement for the additional 28 retrieval missions would require modifications to the present Centaur to accomplish these missions.

A typical mission sequence for synchronous equatorial missions is shown in Figure 4. Approximately 70% of the above 305 expendable missions are in the synchronous equatorial arena.

STAGE DESCRIPTION AND GROUND SERVICING DISCONNECTS

The Centaur stage shown in Figure 5 uses oxygen and hydrogen propellants, containing 25,000 pounds of oxygen and 5,000 pounds of hydrogen in a pressure stabilized stainless steel tank. Oxygen is aft, separated from the hydrogen by a double wall evacuated stainless steel intermediate bulkhead. The two Pratt & Whitney RL10A-3-3 engines provide a total thrust of 30,000 pounds at a nominal specific impulse of 444 seconds. A hydrogen peroxide auxiliary system provides reaction control during coast as well as turbine drive for the tank-mounted boost pumps which feed the main engine turbopumps. Aluminized Mylar radiation shielding provides thermal protection during mission coast periods, significantly reducing the heating rates from the previous Centaur configurations.

The Centaur is presently designed with 3 basic types of disconnects: (1) individual ground disconnects, (2) umbilical panels, and (3) airborne disconnects. These disconnects contain all fluid, instrumentation, and electrical connections required for the Centaur. The individual disconnects are listed below.

Individual Ground Disconnects

- LH_2 fill & drain
- LO_2 fill & drain
- Ground heating for aft bulkhead
- Equipment module air conditioning

Umbilical Panels

- Aft panel
  - Fuel tank pressurization
  - LO_2 tank pressurization
  - Helium charge
  - Helium chilldown
  - Vacuum line (intermediate bulkhead)
- Forward panel (5 electrical plugs, one pneumatic disconnect)
  - Electrical functions
  - Main power
  - Spacecraft electrical
  - Spacecraft electrical
  - Propellant utilization and computer functions
  - Helium purge

The airborne disconnects are composed of systems that are disconnected subsequent to launch, either at fairing separation or Centaur staging. These include the following items.

- O_2 vent
- H_2 vent
- He chilldown vent
- Electrical staging disconnect in aft wiring tunnel
- Instrumentation staging disconnect in aft wiring tunnel
- Purge staging disconnect in aft wiring tunnel
- H_2O_2 vent (emergency outflow)

Most of these functions must be accommodated in adapting the Centaur to the Shuttle and are used as the basis for the integration/operations investigation.

CENTAUR/SHUTTLE INTEGRATION

The method of integrating the Centaur into the Shuttle is dependent upon the operational mode selected. Although there are a variety of launch and operational modes that can be considered, they generally fall into two major categories: (1) tanking the Centaur while in the cargo bay of the Orbiter on the ground, (2) launching the Centaur empty and subsequently transferring excess propellants from the Orbiter to the Centaur once main engine shut down has been accomplished in the Orbiter.

1. Ground Tanking – Two ground tanking schemes can be considered. The first tanking mode investigated is a system wherein the Shuttle and Centaur are tanked separately on the ground. This scheme leads to the minimum interface between the Centaur and the Shuttle since all Centaur interfaces, with the exception of some electrical command, control, and instrumentation monitoring, are located in the cargo bay door of the Shuttle and routed overboard to the ground servicing systems.

The second system considered for ground tanking is identical to that for the first mode except that tanking of the Centaur is accomplished through a system integrated with the OMS (Orbit Maneuvering System) propellant system, eliminating the need for separate tanking facilities for the Centaur.

Separate Tanking – A typical operational sequence of the first system is shown in Figure 6. The Centaur is first loaded into the Shuttle Orbiter, the Orbiter and Booster are then mated and transferred to the launch pad. The Centaur/ground interfaces are then connected through one of the cargo bay doors while the other door is open. The second door is then closed and the system is ready for propellant loading and launch. Following the Booster and Orbiter boost phase of the operation, the Centaur is deployed to initiate its missions. If an abort situation should occur during the Shuttle operation the Centaur will jettison its propellants through overboard dump provisions located in the door of the cargo bay.

The external interfaces generally consist of two sets of disconnects. The first set of disconnects is located on the skin line of the Orbiter cargo bay door. These are ground disconnects and are disconnected at Space Shuttle liftoff. The second set of disconnects is between the cargo bay door and the Centaur vehicle; they are referred to as the Centaur deployment disconnects. They are disconnected just prior to opening the cargo bay doors and deploying the Centaur. A third disconnect set includes any required connections, electrical signals between the Centaur, and Support Adapter or Orbiter. These disconnects are separated during deployment when the Centaur is released from the Orbiter and adapter. A schematic of this installation system is shown in Figure 7.

All Centaur ground disconnects are located on either a forward or an aft panel. The fore and aft Centaur/Orbiter disconnect panels are both located on the starboard cargo bay door. These units are bolt-on Orbiter kits and are installed in the cargo bay door by removing access panels. The Orbiter disconnect kits include the female halves of the outboard ground disconnects and the male halves of the inboard Centaur disconnects. The Centaur disconnects are attached to a retractable panel which will "pull" the disconnects before the cargo bay door is opened. The retraction mechanism can be hydraulic or pneumatic cylinders or electrically operated ball screws. Since the disconnects are all aligned and may be released simultaneously, only one retractable panel is required in each location. The fluid lines between the retractable Centaur panel and the fixed ground panel will be bellows or telescoping tubes to allow for the relative movement between the two panels.

The following external ground disconnect functions are required with this configuration.

Aft Disconnect Panel

- Fuel tank pressurization
- LO_2 tank pressurization
- H_2O_2 emergency vent
- Helium charge
- LH_2 fill and drain
- LO_2 fill and drain
- Ground heating
- O_2 vent (slip tube)

Forward Disconnect Panel

- 5 electrical plugs
- Helium purge
- H_2 vent (slip tube)

The aft Centaur/Orbiter disconnect panel kit will include five helium bottles used to provide tank pressurization to expell the Centaur propellants in an abort or emergency situation. Provisions must be made to supply the proper fluids and gases on the ground and duct away the stage ventage. As shown conceptually in Figure 6 a separate umbilical should be provided to accommodate these requirements, particularly in regard to propellant tanking. It should be possible to integrate the ground tanking facilities for the Orbiter and Centaur such that only propellant supply ducting and controls need be added to accomplish tanking. This type of installation provides the maximum autonomy for the Shuttle third stage, since its tanking, servicing and control functions are independent of the Shuttle systems. The ground functions and requirements would be very close to those presently encountered when launching from a standard launch vehicle.

Integrated Tanking – The second ground tanking mode considered has the Centaur and Shuttle propellant systems interconnected to allow ground tanking of the Centaur to be accomplished through the Shuttle propulsion system. A schematic of the propellant system is shown in Figure 8. This concept eliminates the need for separate external fill and drain systems for the Centaur. All other disconnects remain installed on the door in a manner similar to that of the system using separate tanking. While eliminating the need for separate tanking facilities this concept does require close integration between the Shuttle and the Centaur during tanking. A disconnect is located in the cargo bay between the Centaur propellant system and the Shuttle propellant system, which is retracted prior to deployment of the Centaur. This scheme allows the transfer of propellants back into the Shuttle system from the Centaur, which may be useful in an abort situation to provide additional impulse to the Shuttle and/or provide a means for dumping propellants through the Orbiter system.

2. In-Flight Propellant Transfer – The other operational mode considered for the Centaur is the launching of an empty Centaur which is subsequently filled from the propellants remaining in the Shuttle once the Orbiter main engines have completed their firing. If the orbit maneuvering tanks are filled completely, excess propellants will be available for use in the Centaur since the OMS ΔV requirements are quite modest for this application (approximately 500 ft/sec). In addition, the launch of a light payload (i.e., empty Centaur) results in propellants remaining in the Orbiter main tanks after main engine shutdown. The requirement for tapping into the main tank propellant system will be dependent upon the final Shuttle characteristics which evolve from the study.

A typical operational sequence for this concept is shown in Figure 9, and a schematic of the installation is shown in Figure 10. The Centaur is then tanked from propellants remaining in the Orbiter tanks during the coast from 50 to 100 n. mi. The tanking mode is accomplished with auxiliary transfer pumps supplied with power from either the Shuttle power supply or an auxiliary power unit.

The propellant pumping unit could be installed as a modular package at the cargo bay interface and would be easily removed for alternate payload missions. The fairly constant propellant flow rate when filling the Centaur may allow the pump to accurately measure the propellants transferred to insure sufficient remaining OMS fuel and oxidizer for retro burn.

There are two methods of achieving propellant orientation during transfer, namely, capillary devices and propellant settling.

1. Capillary Devices – A system of capillary screens will be required in the OMS propellant tanks. Although vapor ingestion would not create a serious condition during propellant transfer, it is still preferable to avoid such an occurrence. An undesirable effect would be the uncertainty about the quantity of propellant transferred. Furthermore, two-phase flow could affect pump performance, if a pump were employed to effect propellant transfer. Vapor ingestion can be prevented by installing fine mesh screens across the OMS tanks. A preliminary analysis indicated that a 100μ screen (in each tank) located at the station of anticipated liquid residual would readily permit maximum flow rates of 40 lb/sec LO_2, 8 lb/sec LH_2 without vapor penetration of the screens.

If additional propellant is required from the Orbiter's main tanks this can only be obtained by settling, since high boiloff rates in the un-superinsulated main tanks would prohibit the use of screens.

2. Propellant Settling – For this propellant orientation technique, either engine thrust or main tank venting may be considered to orient the propellants. The selection of the type of attitude control system for the Orbiter will have a significant effect on the feasibility of using this system for propellant settling. An integrated attitude control system would likely provide sufficient propellant to allow settling for the entire duration of propellant transfer. A separate attitude control system would likely be limited in its capacity and would not be capable of providing settling for the required duration. The use of main tank ventage may provide sufficient acceleration for maintaining propellant at the tank outlets and should be investigated further if this technique appears attractive.

The total tanking time (including childown) is estimated to be approximately 1/2 hour, well within the coast phase time available of 45 minutes.

The advantages of such a concept are as follows.

1. Simplification of Centaur by deleting all ground propellant conditioning equipment

2. Safe abort of Orbiter without fueled stage in cargo bay

3. Simplification of ground support equipment and Space Shuttle launch countdown

The use of this type of launch sequence allows the handling of the third stage for the Shuttle to approach that required for an inert payload. Ground insulation, purges and ground venting systems can be deleted, offering the simplest ground servicing and ground hold conditions. The problem of low or zero "g" propellant transfer must be addressed in the Shuttle system, but this must be resolved at some time for other applications and payloads in any case. An isometric installation is shown in Figure 11.

TANKING MODE COMPARISONS

A summary of the different tanking modes is given in Figure 12. The term external interface refers to the interface between Centaur and ground, while the term internal interface refers to interfaces between the Centaur and Shuttle within the cargo bay. The column, "Shuttle Performance", refers to the effect the particular tanking mode may have on the Shuttle. In the case of the ground-tanked Centaur, with separate fill and drain systems, a minor decrease is in useful payload results from the requirement to carry the separate helium bottles for abort. The increase in performance in the other two cases results from the possibility of utilizing propellant sharing between the two stages (i.e., using propellant that may be required for abort as useful impulse propellant for the Centaur once the main abort regime has been passed).

The mode selected, whether it be one of those shown, or some concept combining features of each, will be dependent upon the requirements, capabilities, and operating mode of the Shuttle, along with the GSE requirements, checkout, and ease of operations during the system launch sequence.

The ease of handling, servicing, checkout and launch must be considered in selecting the proper operating mode. The concepts shown above provide some insight into the type of requirements and may be used as the basis for further detailed study.

STRUCTURAL SUPPORT

The type of support system used can effect ease of operation, handling, checkout, and accessibility. The Centaur is designed for a relatively uniform distributed axial load transfer at an attachment ring located at the meridian of the LO_2 tank. Lateral loads are carried by the Centaur structure as bending moments. The capability to carry these loads is dependent on the vehicle tank pressure and a distributed load transfer capability.

For very high lateral g forces, such as those which occur during Orbiter landing, lateral support points can either be located on the Centaur stub adapter or depending on the configuration of the Centaur payload, on the payload itself. This will help in reducing the moment which the Centaur must carry and increase its lateral g acceptable operating constraint.

Some of the methods that have been considered for vehicle support are shown in Figures 13 and 14.

The top system in Figure 13 consists of a forward deployment mechanism attached to the forward end of the Centaur stub adapter. The adapter shown positions the Centaur as far aft as possible in the cargo bay and is approximately 15 ft in diameter to allow for a wide variation in payload geometry without affecting the Centaur interface locations.

The system shown on the bottom has the forward deployment mechanism attached to the aft Centaur interface ring. This adapter is relatively short and is not dependent on payload configuration. The Centaur, however, is located upside-down with respect to the Orbiter. In the ground tanking mode the Centaur must be oriented right-side-up with respect to the Orbiter. The Centaur's propellant loading sequence is based on a top-up Centaur. Ground tanking of an inverted Centaur would require a complete redesign of the propellant tank fill, drain and vent systems and propellant measuring system. Also a complete structural analysis would have to be performed to evaluate the effect of the high negative accelerations imposed on the Centaur during Shuttle launch. For the on-orbit tanking mode the Centaur position is relatively unimportant. A loads analysis would again be necessary for launching an upside-down empty Centaur, but no serious problems are anticipated.

The concept shown at the top of Figure 14 has the aft deployment mechanism attached to the aft Centaur interface ring. The adapter is relatively short and the Centaur is oriented right-side-up with respect to the Orbiter.

The concept at the bottom of Figure 14 has the cradle deployment mechanism attached to the aft Centaur interface ring. The adapter that performs this function must necessarily be rather large to transfer the distributed Centaur load to the cradle with a lateral offset of approximately four feet. A support system similar to that shown at the top of Figure 14 appears to be the desired method for the following reasons.

1. Aft end distributed load removal corresponds with present Centaur flight mode.

2. Efficient aft cargo load transfer appears probable.

3. The Centaur has the greatest payload capacity when it is supported at the aft end by a uniformly loaded support capable of carrying the full bending moment, and lateral load support capability on the stub adapter to reduce the total moment which must be reacted.

CONCLUSIONS

1. Preliminary investigations showed that the Centaur integration into the Space Shuttle is feasible.

2. Minimum impact on GSE should be obtainable.

3. Selection of operating mode is dependent on Shuttle configuration and ground support facilities. Ground operations must be considered in evaluating complete system integration.

4. Space Shuttle design must consider "third stage" integration requiring close phasing of study activity.

ACKNOWLEDGEMENT

Acknowledgement is given to Mr. Edward Bock, Senior Design Engineer at Convair Aerospace Division, for contributing the design input to the study.

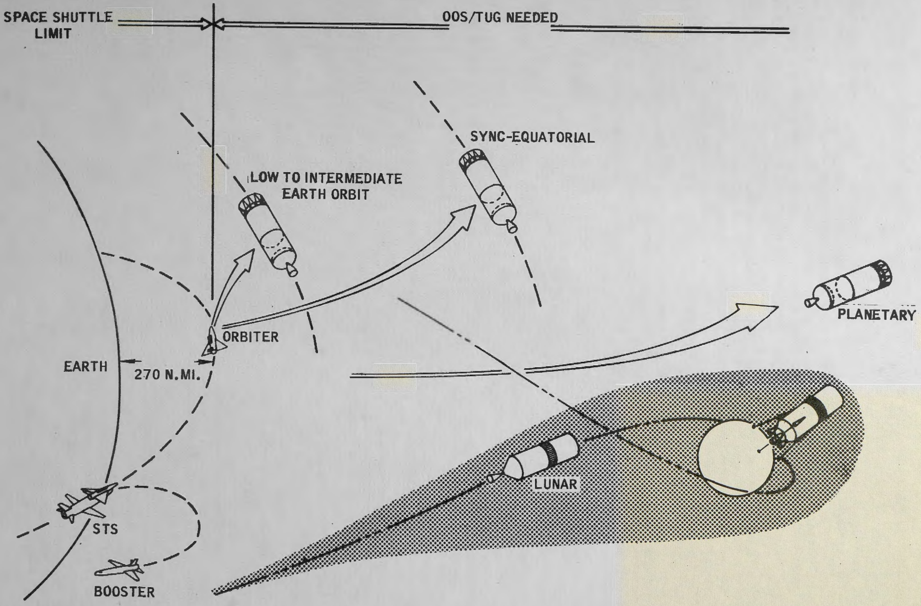

Figure 1. Potential OOS-Tug Missions.

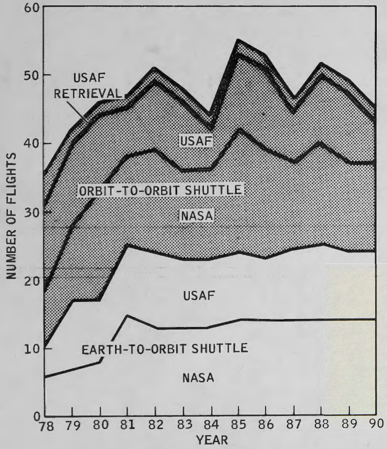

Figure 2. Orbit-to-Orbit Traffic (1978-1990).

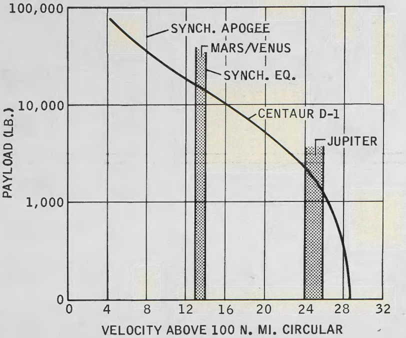

Figure 3. Performance of Centaur D-1T.

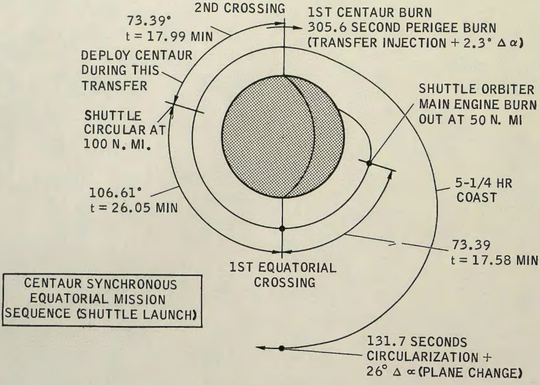

Figure 4. Centaur Synchronous Equatorial Mission Sequence (Shuttle Launch).

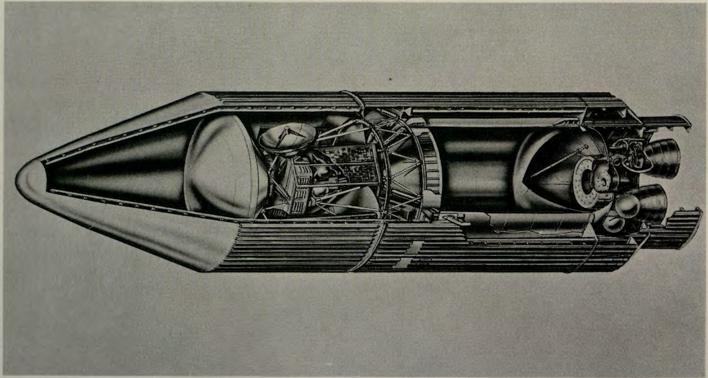

Figure 5. D-1T Centaur.

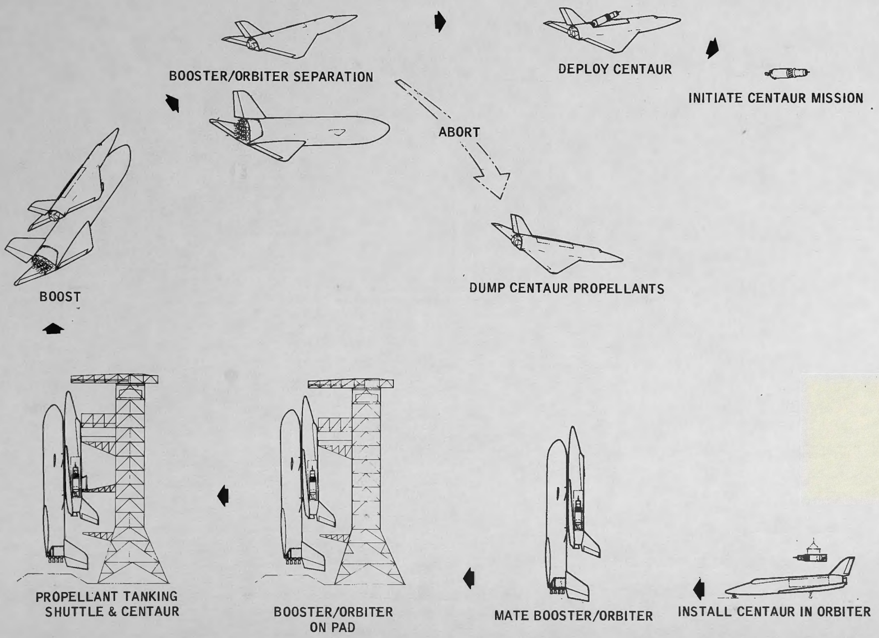

Figure 6. Separate Ground Tanking.

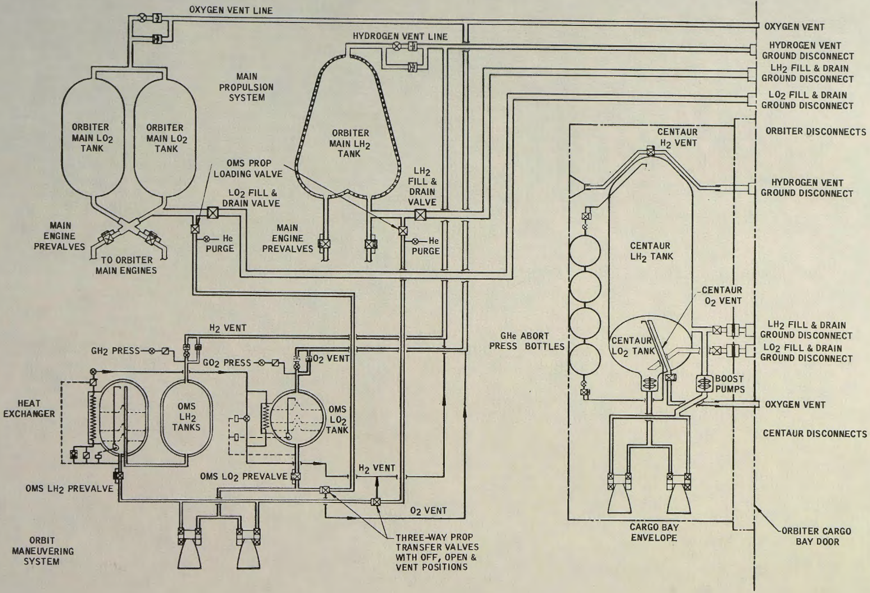

Figure 7. Separate Ground Tanking.

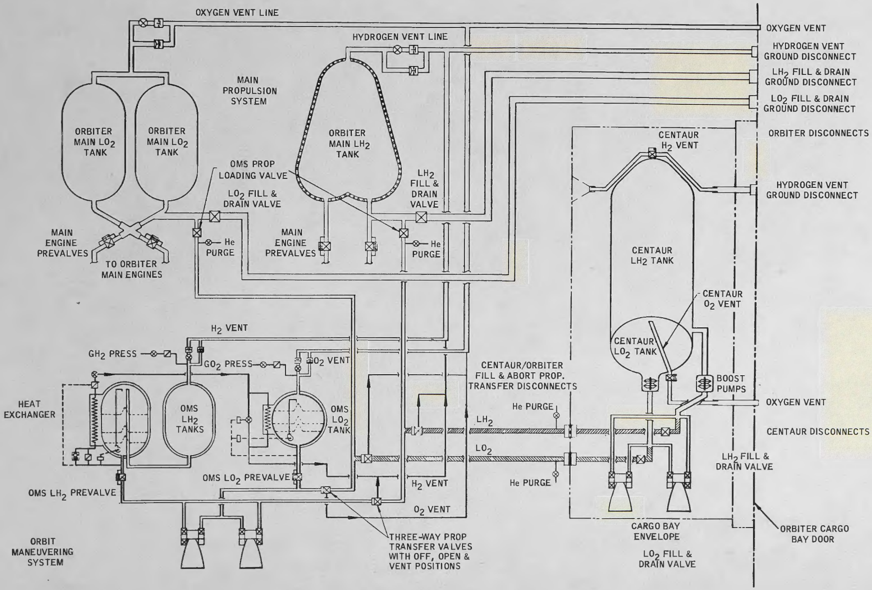

Figure 8. Integrated Ground Tanking.

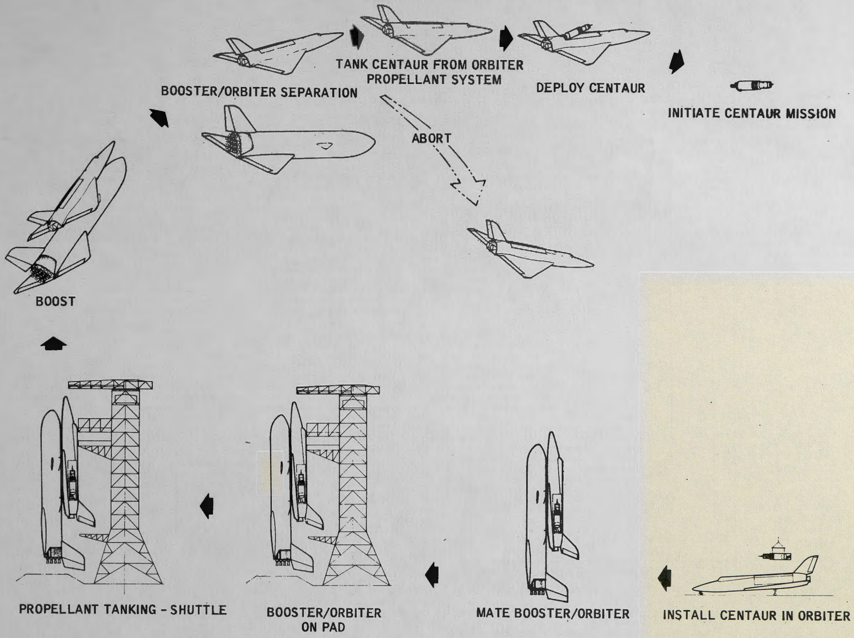

Figure 9. In-Flight Propellant Transfer.

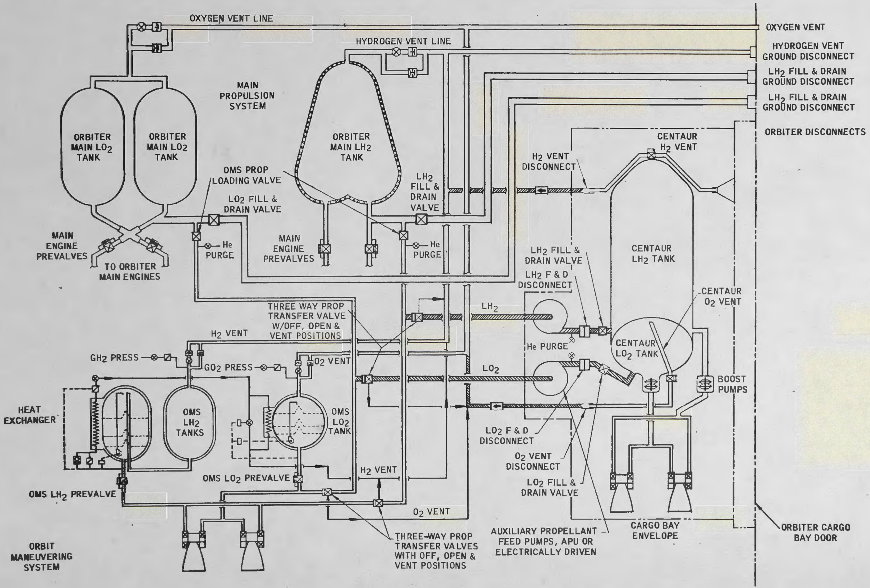

Figure 10. In-Flight Propellant Transfer.

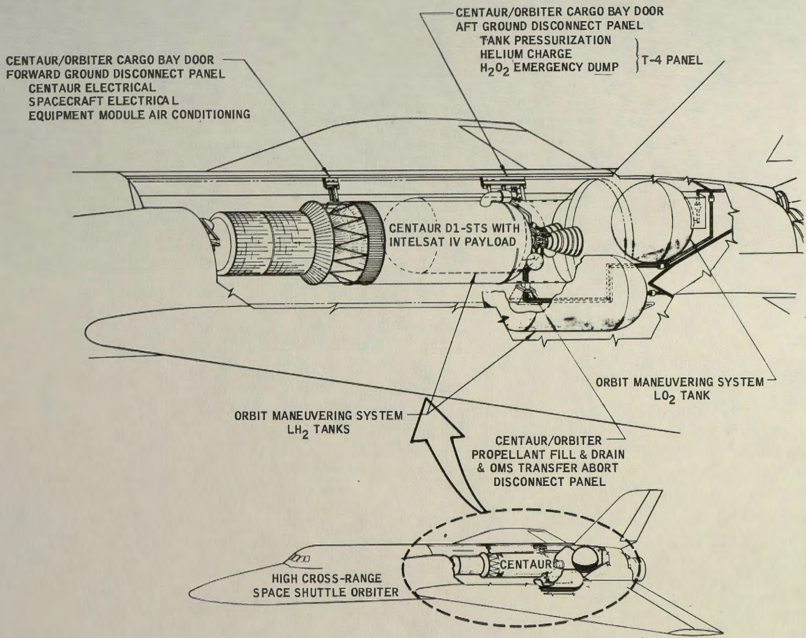

Figure 11. Centaur Installation in Shuttle.

TANKING MODE	SHUTTLE INTERFACES / OPERATIONS	ABORT	SHUTTLE PERFORMANCE	EFFECT ON CENTAUR
1. GROUND-TANKED CENTAUR, SEPARATE TANKING	MAX. EXTERNAL MIN. INTERNAL / INDEPENDENT GROUND OPERATIONS	REQUIRES DUMPING PROPELLANTS EXTERNALLY	MINOR DECREASE	MINOR INTERFACE REORIENTATION, F&D SYSTEM MODIFICATION
2. GROUND-TANKED CENTAUR, INTEGRATED TANKING	EXTERNAL AND INTERNAL / INTEGRATED GROUND OPERATIONS	MAY REQUIRE EXTERNAL DUMPING	SIGNIFICANT INCREASE	MINOR INTERFACE REORIENTATION, F&D SYSTEM MODIFICATION
3. IN-FLIGHT TANKING OF CENTAUR	MIN. EXTERNAL MAX. INTERNAL / MODE DEPENDENT ON SHUTTLE PERF. & CONFIG.	NO PROPELLANT DUMPING REQUIRED	SIGNIFICANT INCREASE	MINOR INTERFACE REORIENTATION F&D SYSTEM MODIFICATION, DELETION OF GROUND INSUL. & PURGES

Figure 12. Tanking Mode Summary, Centaur OOS.

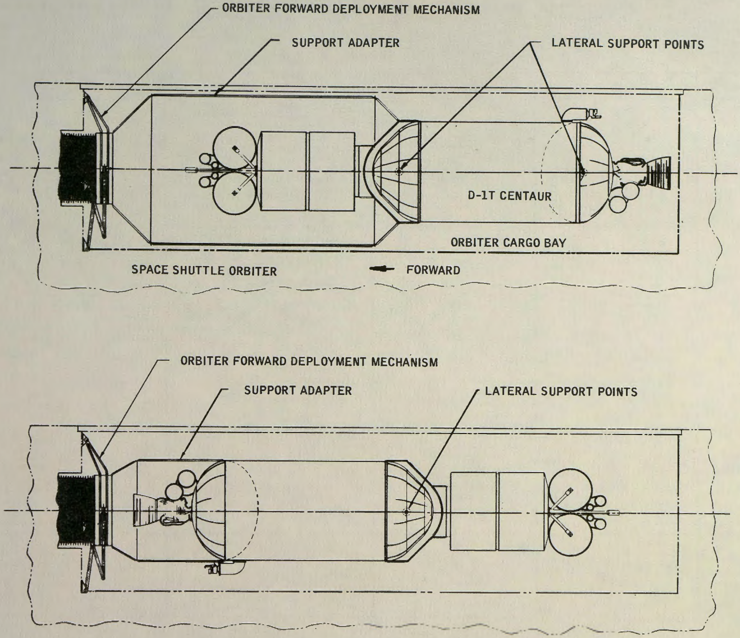

Figure 13. Centaur/Shuttle Structural Attachments.

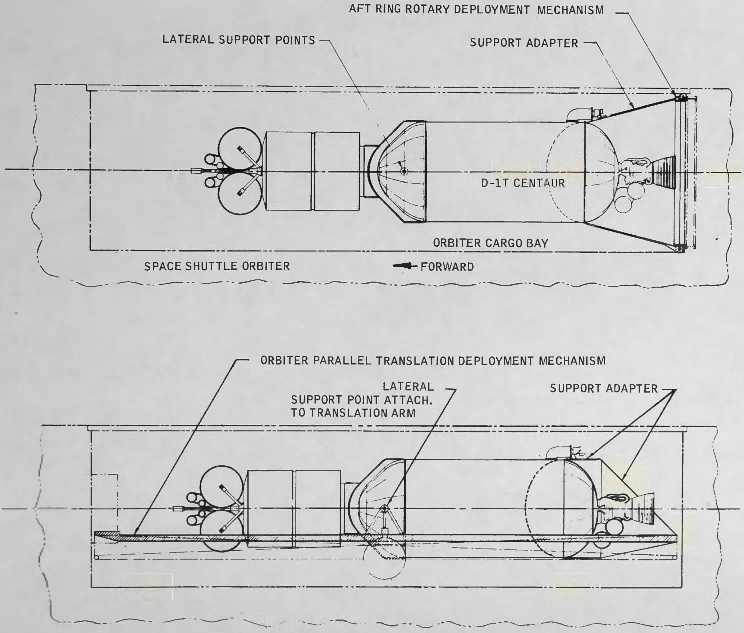

Figure 14. Centaur/Shuttle Structural Attachments.